Coronal Heating and the Magnetic Field in Solar Active Regions

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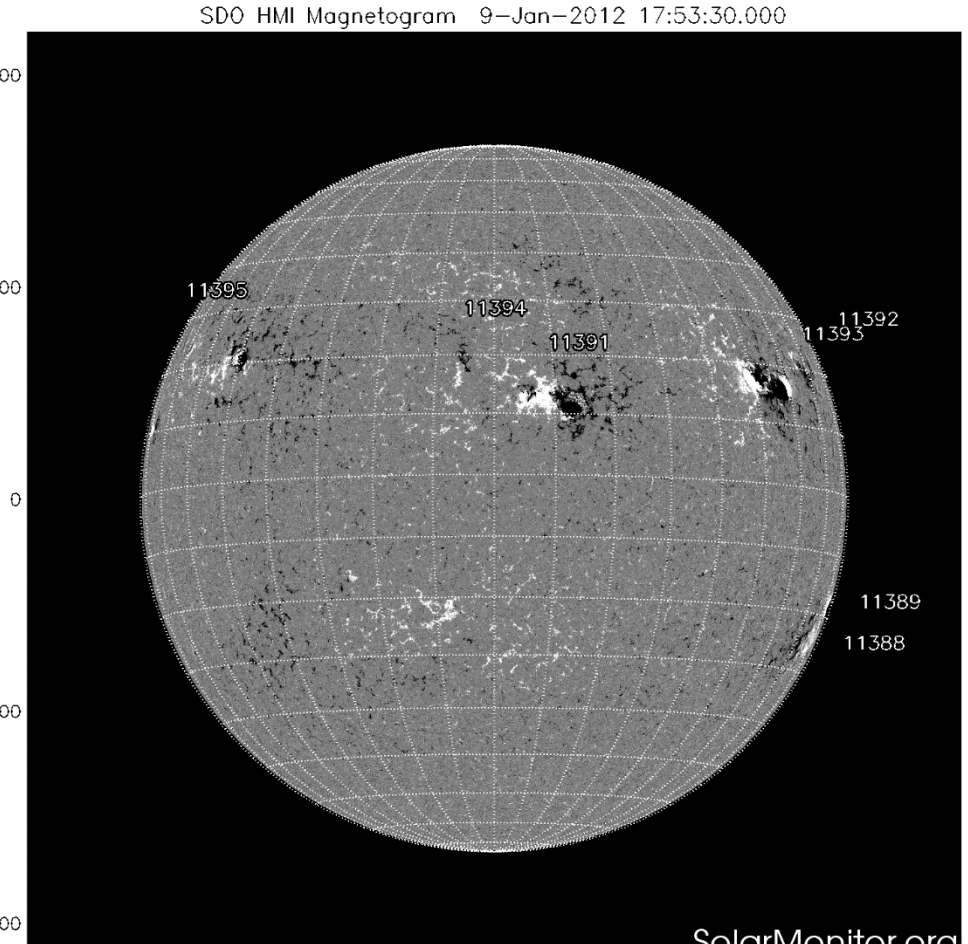
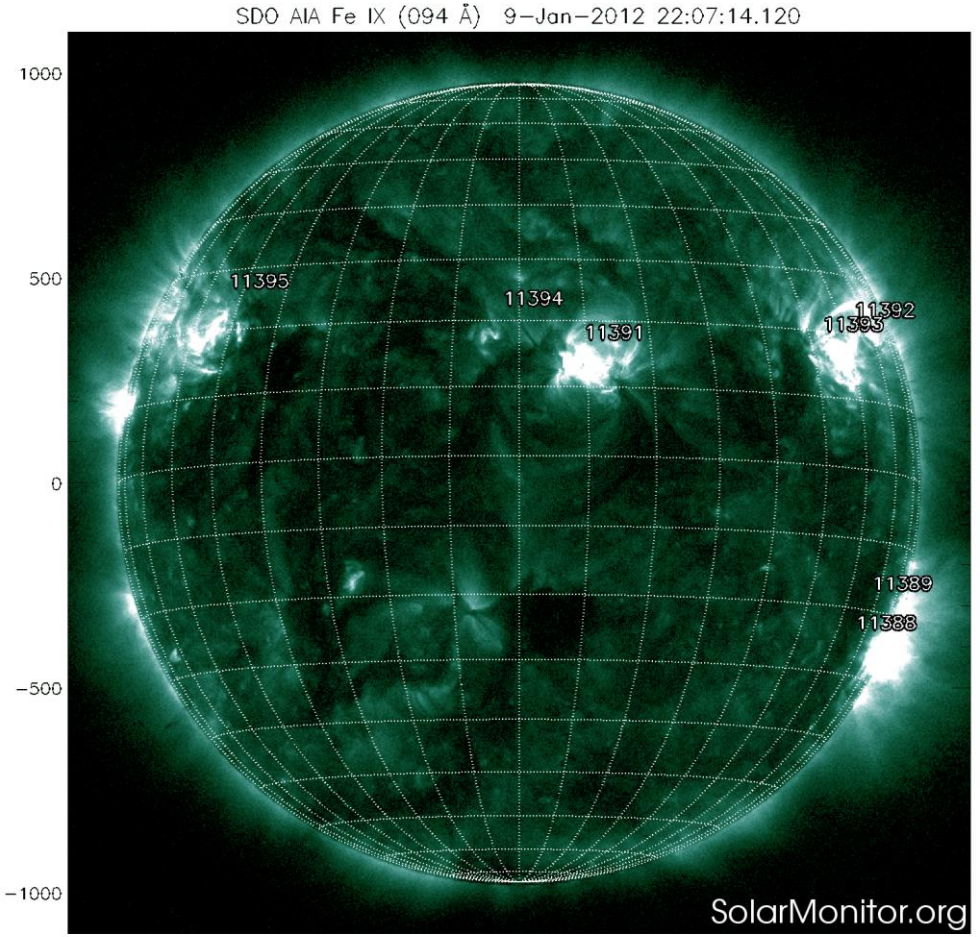


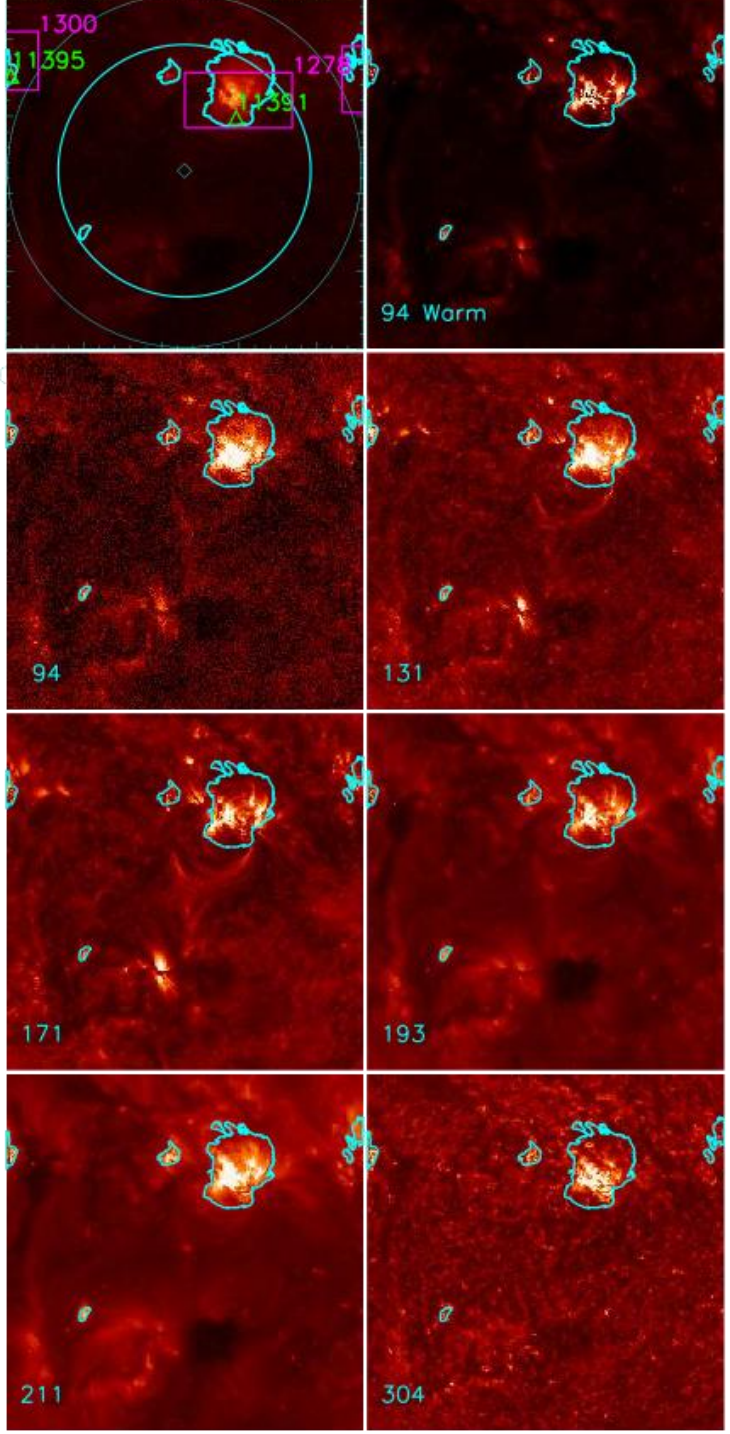


Previous Results

- Falconer 1997 found that coronal X-ray luminosity was correlated with length of strong-shear, strong-field neutral line.
- Fisher et al 1998 found that coronal X-ray luminosity was correlated with several magnetic parameters, many of these were correlated with each other. The parameter with the best correlation was total magnetic flux. Once the luminosity correlation with total magnetic flux was controlled for, none of the others showed a strong correlation with luminosity.
  - Fisher did not have a neutral line length measure

Modern Observations

- With high cadence SDO/AIA observations, and SDO/HMI vector magnetograms observations, it is easy to do a fall up study with a huge sample.
- To simulate X-ray luminosity, we use 94H Warren et al (2012), which subtracts off an estimate of the cooler lines intensity in the 94 angstrom filter.
- Only use non-Flaring times.



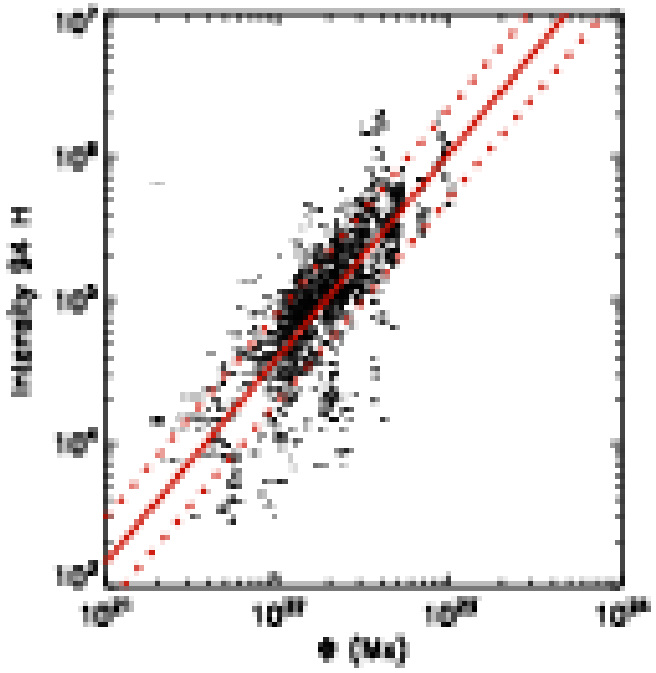
Correlation of Measurements

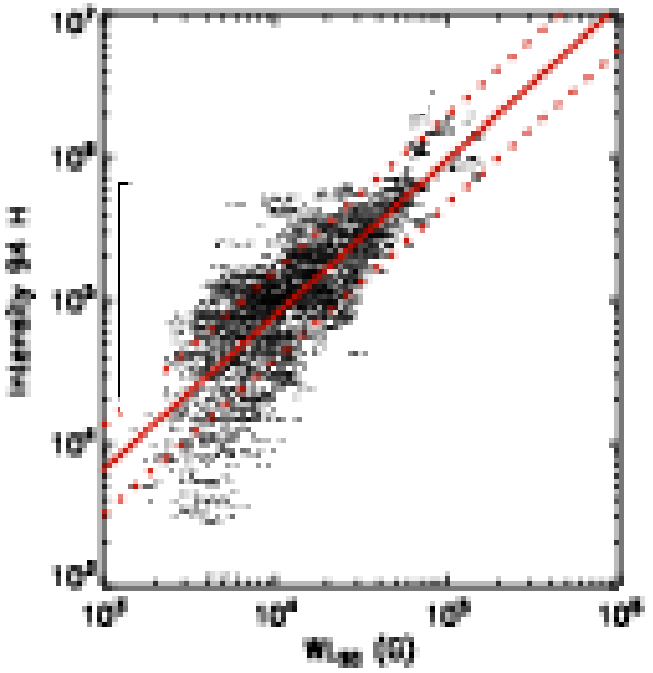
	ϕ	A	L_S	WL_{SG1}	WL_{SG2}	WL_{SS}	R	α_G	INBAL
ϕ	1.00	0.97	0.78	0.70	0.602	0.74	0.68	-0.09	0.16
A	0.97	1.00	0.70	0.62	0.519	0.69	0.59	-0.10	0.09
L_S	0.78	0.70	1.00	0.96	0.88	0.95	0.93	0.13	0.25
WL_{SG1}	0.70	0.62	0.96	1.00	0.971	0.93	0.97	0.22	0.31
WL_{SG2}	0.60	0.52	0.88	0.97	1.000	0.86	0.95	0.29	0.35
WL_{SS}	0.75	0.69	0.95	0.93	0.858	1.00	0.89	0.22	0.20
R	0.68	0.59	0.93	0.97	0.948	0.89	1.00	0.23	0.33
α_G	-0.09	-0.10	0.13	0.22	0.286	0.22	0.23	1.00	-0.03
INBAL	0.16	0.09	0.25	0.31	0.35	0.20	0.33	-0.03	1.00

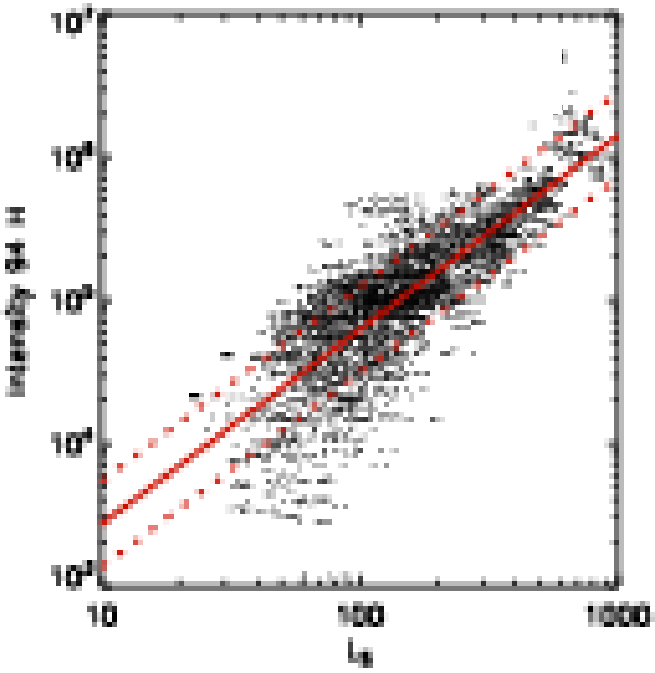
Magnetic Measurements Defined

Symbol	Equation	Integral over	Name
ϕ	$\int \lvert B_z \rvert da$	$\lvert B_z \rvert$>100G	Total Magnetic Flux
A	$\int da$	$\lvert B_z \rvert$>100G	Magnetic Area
L_S	$\int dl$	pBH>150	Neutral Line Length
WL_{SG1}	$\int(\nabla B_z)dl$	pBH>150	Gradient Weighted Neutral Line Length
WL_{SG2}	$\int(\nabla B_z)^2 dl$	pBH>150	Gradient Weighted Neutral Line Length
WL_{SS}	$\int\theta)dl$	pBH>150	Sheer Weighted Neutral Line Length
R	weighted flux near	Neutral line	Scriver's R
α_G	$\alpha_g = \Sigma\left(\frac{\partial By}{\partial x}+\frac{\partial Bx}{\partial y}\right)Bz \Big/ \sum B_Z^2$	$\lvert B_z \rvert$>100G	Magnetic Field Weighted Twist
INBAL	$1-\lvert\phi_+-\lvert\phi_-\rvert\rvert(\phi_+-\lvert\phi_-\rvert)$	$\lvert B_z \rvert$>100G	Flux imbalance

94 H luminosity versus Single Magnetic Parameters







Best Fit

L_S is best, but other measures are almost as good

Tag	Fit		Standard deviation					Spearman				
	A	B	Avg	dif	Unc	sg	%	Avg	Dif	Unc	Sg	%
L_S	2.07	1.36	0.302					0.810				
WL_{SG1}	0.55	1.09	0.312	-0.010	0.007	-1.51	4	0.788	-0.022	0.012	-1.86	3
ϕ	-26.94	1.43	0.313	-0.011	0.019	-0.56	31	0.805	-0.005	0.033	-0.14	42
WL_{SS}	2.72	1.18	0.318	-0.016	0.010	-1.63	7	0.793	-0.017	0.013	-1.29	12
R	1.76	0.78	0.323	-0.021	0.010	-2.04	1	0.775	-0.035	0.017	-2.04	3
A	-20.92	1.31	0.343	-0.040	0.022	-1.81	3	0.760	-0.050	0.039	-1.27	10
WL_{SG2}	0.51	0.74	0.346	-0.044	0.012	-3.79	0	0.724	-0.086	0.023	-3.69	0
Inbal	5.21	3.46	0.479	-0.177	0.027	-6.49	0	0.325	-0.485	0.086	-5.66	0
α_G	5.66	0.08	0.510	-0.208	0.028	-7.31	0	0.063	-0.747	0.067	-11.2	0

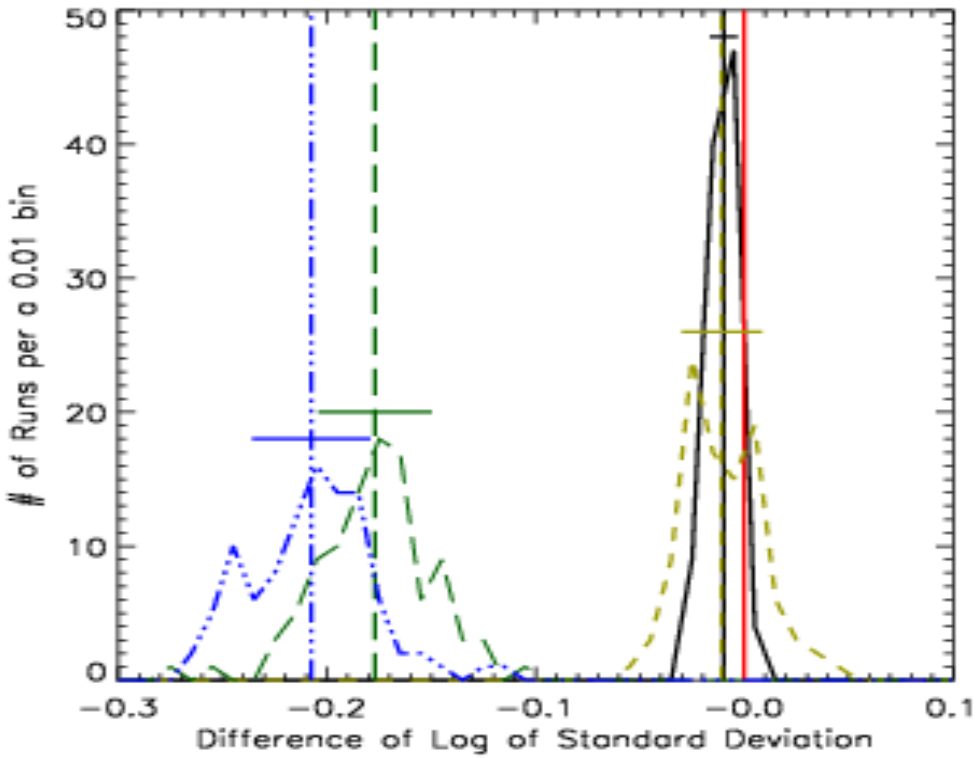
Explanation of Columns

For each of 100 runs, we divide the sample into a control and experiential sample, calculate best fit from the control, and then predict the brightness of each experimental AR. We then find the standard deviation. For each run the difference between the reference (in this case L_S) and the measure is determined

- The average of 100 runs is given under avg.
- The average difference is given next
- The standard deviation of the average difference is next.
- The ratio of the average difference and the standard deviation of the average difference is the next column, this indicates how significant the difference is.
- The percent of the runs that the non-reference was better is next.
- The Spearman rank coefficient for the control is done next, in the same way.

Comparison of Single Parameters as Predictors of AR Luminosity

- . Comparison of four parameters difference of standard deviation relative to L_S. Four histograms are shown WL_{SG1} (black), ϕ (gold), imbalance (green), blue α_G(blue) of the difference of the log of standard deviation relative to L_S from the 100 different runs.
- WL_{SG1}, ϕ are comparable to L_S in predicting AR luminosity, the other two are not



Best Two Parameter Fit to AR Luminosity Relative to Best Single Parameter

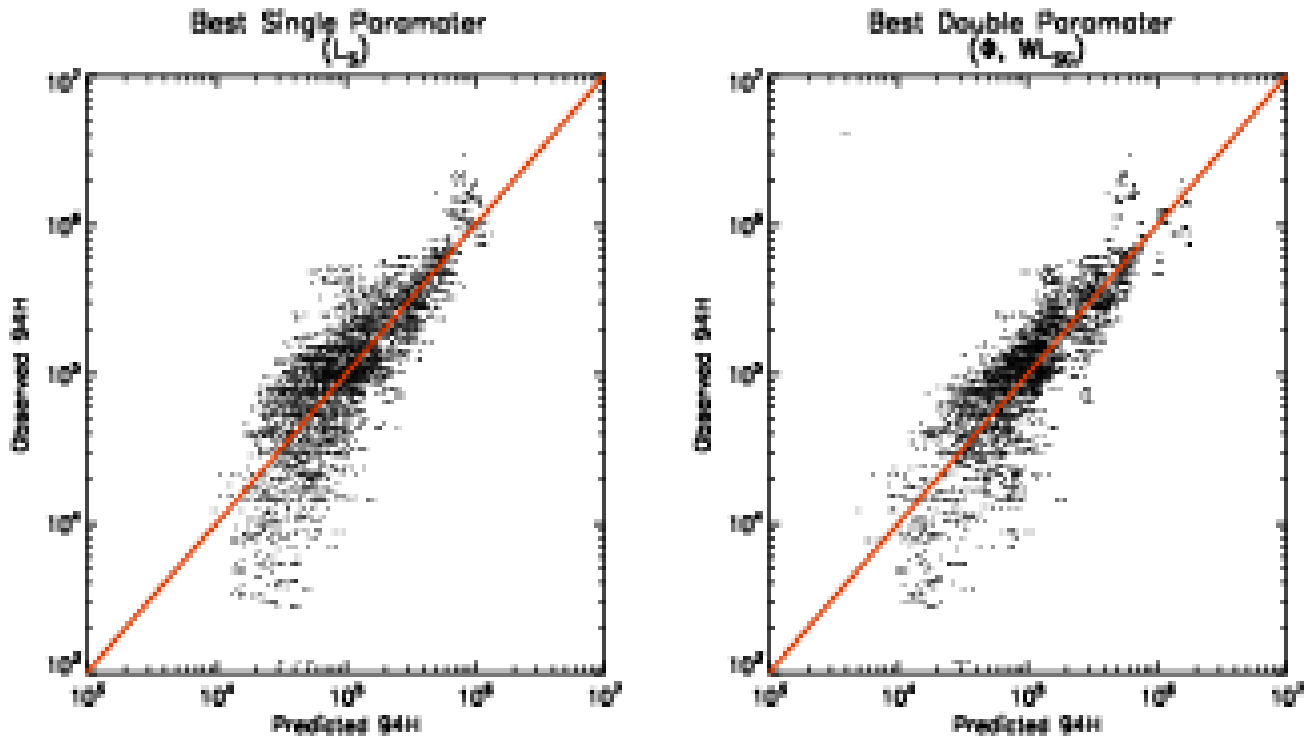
Tag	Standard deviation					Spearman				
	avg	Dif	unc	sg	%	Avg	dif	Unc	Sg	%
$\Phi + WL_{SG1}$	0.272	0.030	0.009	3.22	99	0.865	0.055	0.049	1.13	87
$\Phi + L_S$	0.280	0.022	0.009	2.59	98	0.858	0.048	0.051	0.94	81
$\Phi + WL_{SG2}$	0.275	0.028	0.012	2.38	99	0.857	0.048	0.048	0.99	85
$\Phi + WL_{SS}$	0.282	0.021	0.011	1.85	96	0.853	0.043	0.049	0.88	81
$\Phi + R$	0.274	0.028	0.012	2.29	99	0.862	0.052	0.048	1.08	86
$\Phi + A$	0.312	-0.009	0.017	-0.53	29	0.806	-0.004	0.054	-0.08	47
$\Phi + \alpha_G$	0.307	-0.004	0.019	-0.23	41	0.815	0.005	0.052	0.09	55
Φ+INBAL	0.302	0.000	0.020	0.02	49	0.818	0.008	0.049	0.17	57
$A+WL_{SG1}$	0.273	0.029	0.009	3.19	100	0.860	0.050	0.049	1.02	85

Best Two Parameter Fit to AR Luminosity Relative to Very Best Two Parameter Fit

- There are 4 pairs of measures within 1 sigma, of the very best 2 parameter fits
- When a measure is paired with ϕ, it is always slightly better than paired with A, though never significantly better.

Tag	Standard deviation					Spearman				
	avg	Dif	unc	sg	%	Avg	dif	Unc	Sg	%
$\Phi + WL_{SG1}$	0.272					0.865				
$A + WL_{SG1}$	0.273	-0.002	0.003	-0.565	29	0.860	-0.005	0.005	-0.960	17
$\Phi + R$	0.274	-0.003	0.004	-0.588	26	0.862	-0.003	0.005	-0.598	31
$\Phi + WL_{SG2}$	0.275	-0.003	0.003	-0.890	18	0.857	-0.007	0.004	-1.649	5
$A + R$	0.275	-0.004	0.006	-0.616	24	0.858	-0.007	0.008	-0.836	19
$\Phi + L_S$	0.280	-0.008	0.004	-2.196	2	0.858	-0.007	0.005	-1.515	5
$A + WL_{SG2}$	0.279	-0.007	0.005	-1.387	8	0.848	-0.017	0.009	-1.866	6
$A+ L_S$	0.282	-0.010	0.005	-2.167	2	0.855	-0.010	0.005	-1.771	2
$\Phi + WL_{SS}$	0.282	-0.010	0.006	-1.784	6	0.853	-0.012	0.007	-1.695	3

Best single and Double Parameter Predictor of AR Luminosity



Results

- AR 94H luminosity is correlated with several magnetic parameters
- Some of the magnetic parameters are correlated with each other
- The best single is length of strong field neutral line
- Total Magnetic Flux is almost as good
- The best pair are total magnetic flux and gradient weighted neutral line length, with several others pairs almost as good
  - Can replace total magnetic flux with magnetic area
  - Can replace WL_{SG1} with R or WL_{SG2}.
- Investigation of a 3rd Parameter only finds a 1 sigma improvement.
  - Not shown